Sand Ripple Generation, Evolution and Decay: An Investigation of Physical and Biological Controls

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LONG-TERM GOALS

The central goal of this research is a deeper understanding of bed state adjustment in mobile sandy sediments on the inner continental shelf, and in particular the adjustment(s) to the combined effects of variable fluid forcing and biological reworking of the sediment surface. The work is motivated by the lack of a suitable observational basis for developing and testing models of the temporal evolution of the seabed roughness spectrum resulting from fluid-sediment-biological interactions in environments subjected to transient wave forcing events.

OBJECTIVES

Our primary objective in this first phase of the project is to quantify the rates of ripple degradation and seabed roughness change arising from biological activity on and within the seafloor. The second objective is to compare the measured degradation rates to those predicted by analytic and numerical models of bed roughness change by biological organisms, as a function of spatial frequency spanning the ripple band.

APPROACH

As part of the SAX04 experiment, two instrumented bottom pods, Dalpod1 and Dalpod2, were deployed at the SAX04 site off Fort Walton Beach, and cabled to the *R/V Seward Johnson*. The bottom pod sensors included single-point velocimeters (Nortek Vector and Sontek ADV-O), an upward-looking acoustic Doppler current profiler with wave measurement capability (RDI WavesADCP),

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downward-looking coherent Doppler profilers (CDPs), rotary imaging sonars, and laser-video bed profiling systems. This suite of sensors provided measurements of the surface-to-bottom current profile, the wave directional spectrum, bottom boundary layer turbulence and bottom stress, ripple geometry, and the bed roughness spectrum.

In addition to monitoring naturally-occurring changes in bed roughness, SCUBA divers from the Naval Research Laboratory (NRL) carried out manipulative experiments at the pod locations, introducing both artificial ripples (by raking) and colored sediments in specified initial patterns. These manipulative experiments allowed us to observe the time scales of bottom roughness decay as a function of the spatial scale of the initial disturbance, at times when the physical forcing mechanisms were weak.

Finally, we are comparing the above observations of ripple decay to the predictions of biological seabed disturbance models. A primary focus of the modeling component of the project is a numerical automaton bioturbation model, developed for studies of mixing processes in surficial seafloor sediments by Bernie Boudreau and his group.

WORK COMPLETED

Work during the past year has focused on ripple degradation during the 19-d period following Tropical Storm Mathew, and the environmental conditions during this time. The results for the decay of the bed elevation spectrum obtained from the rotary pencil-beam sonar have been completed. Similar analyses of the higher-resolution bed profiles from the laser-video system are in progress. The cumulative differences in the rotary fan-beam imagery has also been used to provide an independent measure of ripple decay. The analysis and quality control of the hydrodynamic data from the ADCP, ADV-O and Vector data have been completed. The CDP data have been used to extract turbulence intensities and turbulent kinetic energy dissipation rates near the bed. A diffusive model of the ripple decay process has been developed and applied to the observations.

The automaton bioturbation model is being modified for ripple degradation studies by graduate student Dan Reed. Preliminary model runs with subsurface deposit-feeders (i.e. infauna) suggest that 10-cm wavelength ripples persist on time scales of the order of years. Obviously, these results are dependent on the functional groups of organisms in the model, as well as other community and biological parameters. Currently, three functional groups have been implemented: the above-mentioned subsurface deposit-feeders, head-down deposit-feeders, burrow-and-fill mixers (e.g. fiddler crabs). Code for a fourth group (lugworms) is currently being written. Model runs with these groups will be carried out during the coming year, for ripples of different scale. Based upon the SAX04 observations, fish-induced disturbance of the seabed will also need to be incorporated into the model.

RESULTS

Among the primary results from the effort during the past year are the different measures of turbulence in the bottom boundary layer in the presence of relict ripples. Despite the potentially significant impact of relict ripples on wave dissipation rates on shallow sandy continental shelves, there have been very few (and possibly none?) such measurements made in the past. Two independent estimates of the turbulent kinetic energy dissipation rate, ε, are compared in Figure 1. Despite the scatter, the two sets of estimates indicate that dissipation rates were weak, O(10-6) W/kg. These rates are 1 to 2 orders of magnitude less than measurements made in the nearshore zone, consistent with the relatively quiescent

conditions associated with the 1-m significant wave heights, 6-s wave period, and 17-m water depth of these observations. Similarly, the bottom stress was also small ($u_* <$ 1 cm/s), and less than the threshold of grain motion even for the significant waves. A manuscript summarizing the results from the near-bed turbulence measurements, and their implications for estimating wave friction factors in the presence of relict ripples, has been submitted for publication.

A second primary result is a diffusive model for the ripple degradation process. The model provides good first-order fits to the spectral rates of bed elevation decay, and to the time rate of change of spatially-integrated backscatter from the rippled sediment surface. Figure 2 shows an example of the fit in the latter case. Considering the relative simplicity of the model, the fit is surprisingly good. The fits of the diffusive model to the spatial-frequency dependent rates of change of the bed elevation spectrum, and to the rate of change of the spatially-integrated backscatter amplitude, yield independent estimates of the horizontal sediment diffusivity. Encouragingly, these estimates are comparable to previously- reported sediment diffusivities obtained using particle-tracer techniques, when account is take of the enhanced biological activity in the vicinity of the instrument pod (i.e. the refuge effect) and of the horizontal/vertical anisotropy of the diffusive process (manuscript in preparation).

IMPACT/APPLICATIONS

Remote acoustic measurements of the time-rate of change of relict ripple geometry in quiescent conditions provides a new and non-invasive method for estimating the horizontal diffusivity of seafloor sediments. The fact that a diffusive model provides a good fit to the observations indicates that, with knowledge of the natural rates of bioturbation in sandy sediments, quantitative predictions of ripple degradation rates are possible.

This project is directly relevant to questions related to sound scattering from and penetration into sandy marine sediments, and to the arguably broader question of the predictability of ripple geometry on the inner continental shelf. Both questions arise in relation to buried object detection, in relation to the rates of burial or exposure of objects on the seafloor, in relation to temporal and spatial variability in seafloor acoustic scattering, and in relation to predicting the physical conditions (wave heights, currents, etc.) on the inner shelf area at a given time: all “needs-to-know” for naval operations in coastal environments.

PUBLICATIONS

Hay, A.E., 2006, Near-bed turbulence and relict wave-formed sand ripples: Observations from the inner shelf, *J. Geophys. Res.*, submitted.

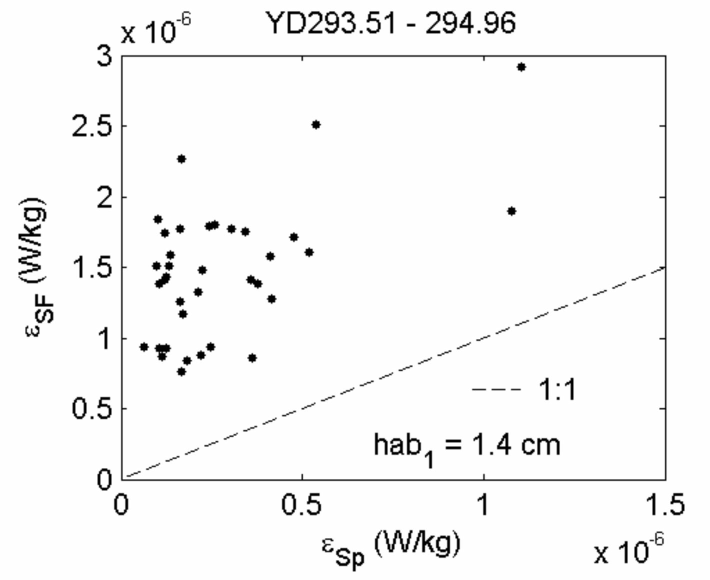

Figure 1. Turbulent kinetic energy dissipation rates near the bed in the presence of relict ripples following Tropical Storm Matthew.

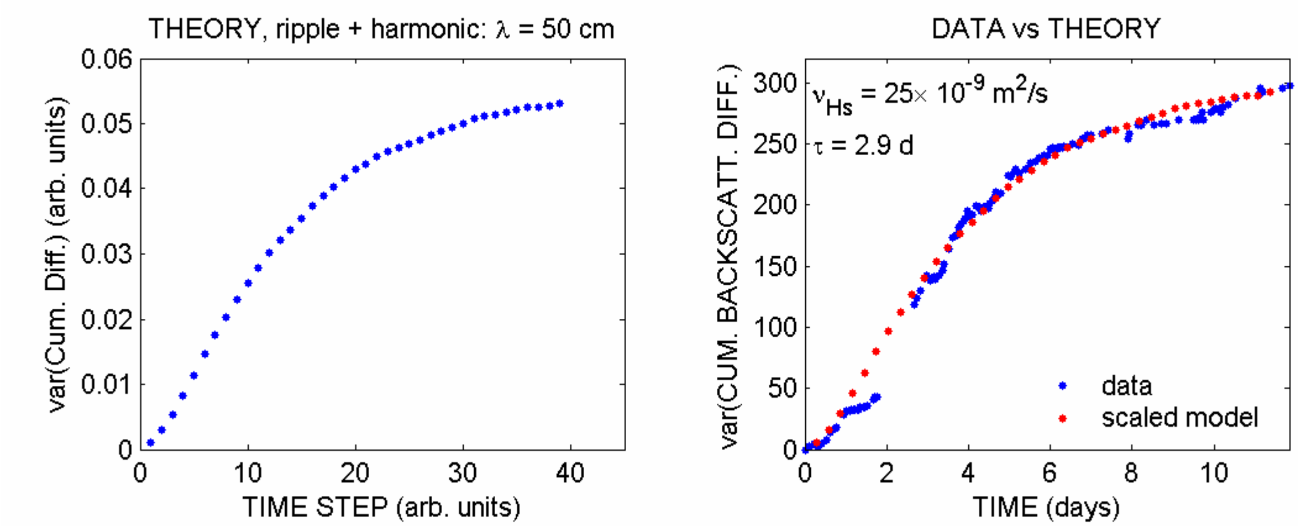

Figure 2. Comparison between theory of spatially-integrated acoustic backscatter from a degrading ripple field and the SAX04 observations. Left panel: theoretical time variation, non-dimensional time and non-dimensional backscatter. Right panel: the theory fitted to the data using stretching coefficients in time and backscatter. Also shown in the right panel are the horizontal sediment diffusivity and the ripple decay time constant yielded by the fit.